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THE FERMILAB MAIN INJECTOR

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Abstract Fermilab has proposed the construction of a new 150 GeV accelerator called the Main Injector. This accelerator will replace the existing Main Ring in all its functions. The Main Injector is expected to perform at a significantly higher level than the Main Ring as measured either in protons delivered per cycle, protons delivered per second, or transmission efficiency. It is anticipated that following construction of this machine the antiproton production rate at Fermilab will exceed 1×10^{11} $\bar{p}$/hour and that a luminosity in excess of 5×10^{31} cm^{-2}sec^{-1} will be supported in the existing collider. Additional benefits accruing from this accelerator include reduction of backgrounds at the collider detectors, potential development of a third interaction region in the Tevatron, and the availability of slow extracted 120 GeV beams year around. Design criteria and paramaters of the Main Injector will be discussed.

INTRODUCTION

In order to provide the opportunity for new physics exploration at Fermilab during the decade of the 1990's a phased upgrade of the existing accelerator complex has been proposed. The goals of the upgrade are a factor of fifty increase in delivered luminosity in the proton-antiproton collider, a threefold increase in the intensities delivered from the Tevatron for fixed target experiments, and the creation of a new capability for delivering high average intensity (~2 μA), intermediate energy (>100 GeV) beams for fixed target physics and test beam experiments.

Fermilab currently operates the highest energy collider in the world. This situation will remain unchanged until the initial operation of the Superconducting Super Collider (or possibly CERN's Large Hadron Collider) sometime in the late 1990's. Today at Fermilab antiprotons and protons are brought into collision at 1.8 TeV in the center of mass with peak luminosities routinely 50% in excess of the design luminosity of 1×10^{30} cm^{-2}sec^{-1}. The recently completed collider run yielded an integrated luminosity, recorded on tape by the CDF detector, of about 5 pb^{-1}. This level should be sufficient for observing the top quark if its mass is less

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than about 100 GeV and heavy Z's and W's up to a mass of about 300 GeV. Fermilab would like to provide the potential for experimenters to double this mass reach during the 1990's.

The planned upgrade of the Fermilab Complex will take place in phases. The first phase is based on optimizing and improving existing facilities. It involves the implementation of new low beta systems at the two interaction regions designated B0 and D0, the use of separators to run a large number of proton and antiproton bunches in the Tevatron, upgrades to the Antiproton Source, implementation of cold compressors to raise the beam energy to 1.0 TeV, and the upgrading of the Linac energy from the present 200 MeV to 400 MeV. All of these projects are presently in progress and are expected to be fully implemented by the end of 1992. The luminosity is expected to rise to about 1×10^{31} $cm^{-2}sec^{-1}$ as a result of these improvements.

Pushing the luminosity up another factor of 5-10 will require the construction of new facilities at Fermilab. Several options have been examined over the past few years with the replacement of the existing Main Ring by a new accelerator, designated "The Main Injector", emerging as the preferred approach for Phase 2 of the upgrade. The construction of this machine will lead to increased antiproton production rates, and improved transmission of high intensity proton and antiproton bunches, which will allow the achievment of luminosities at or in excess of 5×10^{31} $cm^{-2}sec^{-1}$ in the Tevatron Collider. Parameters for the luminosity upgrade are given in Table I. ·

Table I: Luminosity Upgrade Parameters

	Now	Phase 1	Phase 2	
Energy (Center of Mass)	1.8	2.0	2.0	TeV
Protons/Bunch	7×10^{10}	10×10^{10}	33×10^{10}	
Antiprotons/Bunch	3×10^{10}	3×10^{10}	6×10^{10}	
Number of Bunches	6	22	22	
Total Antiprotons	18×10^{10}	66×10^{10}	132×10^{10}	
Antiproton Stacking Rate	2×10^{10}	7×10^{10}	14×10^{10}	$\bar{p}$/hr
Proton Transverse Emittance (95%)	24π	18π	30π	mm-mr
Antiproton Transverse Emittance	18π	18π	22π	mm-mr
β^*	0.65	0.5	0.5	meters
Proton Beam Size (rms) at IR	52	38	48	μm
Antiproton Beam at IR	45	38	41	μm
Luminosity	1.6×10^{30}	1.0×10^{31}	5×10^{31}	$cm^{-2}s^{-1}$
Beam-beam $\Delta\nu$/crossing	.002	.004	.008	
Number of Crossings	12	2	2	
Beam-beam $\Delta\nu$ Total	.026	.008	.016	

THE MAIN INJECTOR

The Main Injector (MI) is a new 150 GeV accelerator which will replace the existing Main Ring in all its functions. The ring is approximately half the circumference of the Main Ring and will be situated on the southwest side of the Fermilab site, tangent to the Tevatron at F0, as shown in Figure 1. Following construction of the Main Injector all Main Ring operations will cease. Major impacts on both the collider and fixed target programs at Fermilab are expected as detailed below.

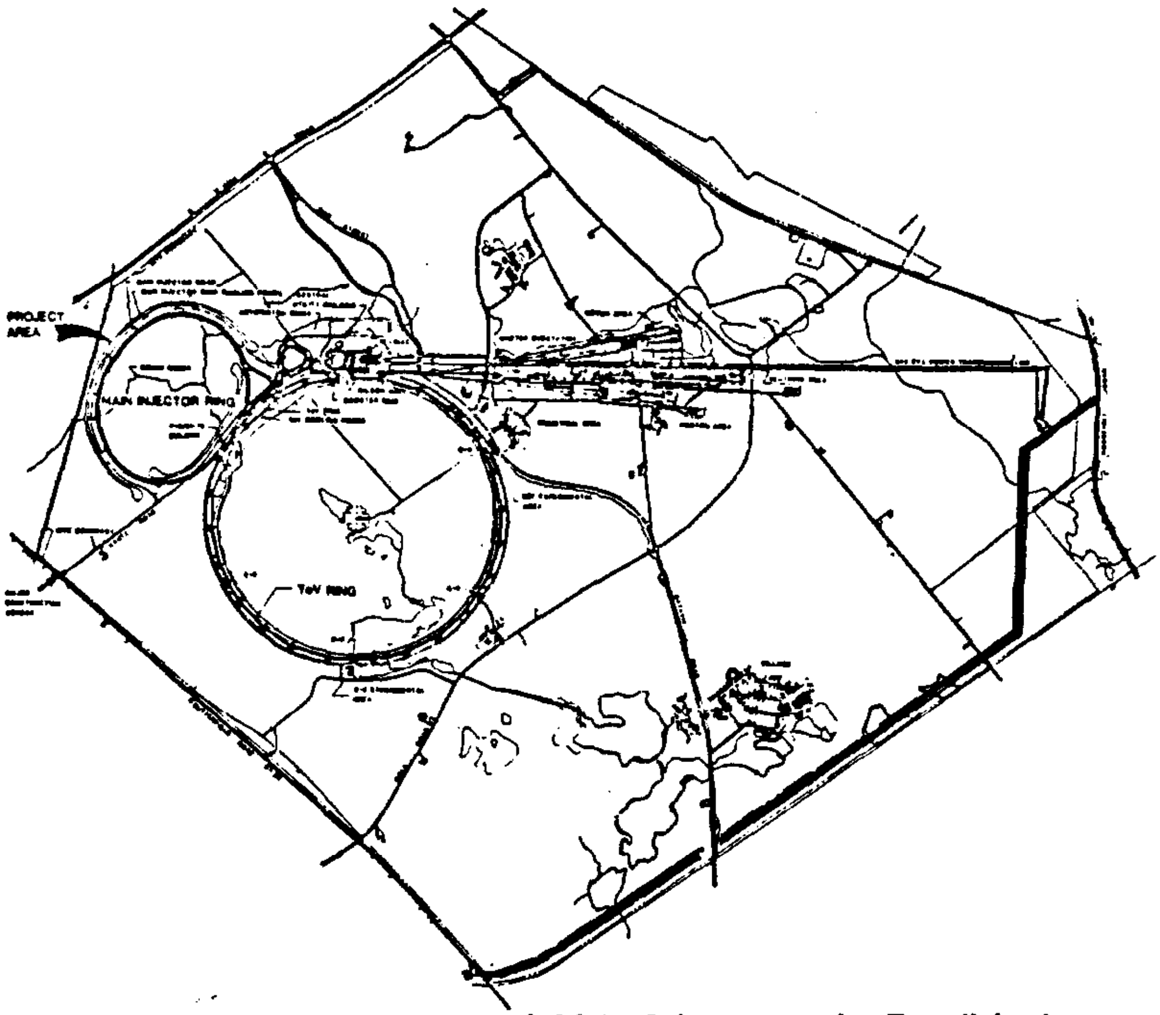

FIGURE I: Location of the proposed Main Injector on the Fermilab site.

The Main Injector parameter list is given in Table II. The primary design criterion for the MI is that it remove the existing bottleneck in the delivery of intense proton beams either to the Tevatron or to the antiproton production target. The present aperture of the Main Ring (12π mm-mr as measured in normalized units) is significantly smaller than that of the 8 GeV Booster (20π mm-mr). As a result the Booster is typically run at about two thirds of its capablity during normal operations. The restricted aperture in the Main Ring is due to perturbations to the ring which have been required for the integration of overpasses and new injection/extraction systems related to operations with antiprotons. Following the 400 MeV Linac upgrade the Booster aperture will increase to 30π mm-mr due to increased adiabatic damping within the new linac and the Booster/Main Ring mismatch will become even more dramatic.

Table II: Main Injector Parameter List

Circumference	3319.4 meters
Injection Momentum	8.9 GeV/c
Peak Momentum	150 GeV/c
Minimum Cycle Time (@120 GeV)	1.5 sec
Number of Protons	3×10^{13}
Harmonic Number (@53 MHz)	588
Horizontal Tune	22.42
Vertical Tune	22.43
Transition Gamma	20.4
Natural Chromaticity (H)	-27.5
Natural Chromaticity (V)	-28.5
Number of Bunches	498
Protons/Bunch	6×10^{10}
Transverse Emittance (95%, Normalized)	20π mm-mr
Longitudinal Emittance	0.4 eV-sec
Transverse Acceptance (@8.9 GeV/c)	40π mm-mr
Longitudinal Acceptance	0.5 eV-sec
β_{max} (Arcs)	57 meters
β_{max} (Straight Sections)	80 meters
Maximum Dispersion	2.2 meters
Number of Straight Sections	8
Length of Standard Cell	34.3 meters
Phase Advance per Cell	90 degrees
RF Frequency (Injection)	52.8 MHz
RF Frequency (Extraction)	53.1 MHz
RF Voltage	4 MV
Number of Dipoles	300
Dipole Length	6.1 meters
Dipole Field (@150 GeV/c)	17.3 kGauss
Number of Quadrupoles	202
Quadrupole Gradient	196 kG/m

The Main Injector is designed to have a transverse acceptance (40π mm-mr) larger than that of the Booster following the Linac upgrade. The Main Injector should be capable of accelerating 5×10^{12} protons per Booster batch for antiproton targetting, as compared to 1.7×10^{12} in the Main Ring, and should be capable of delivering up to 6×10^{13} protons in two MI batches to the Tevatron, as compared to 1.8×10^{13} using the Main Ring. It is anticipated that the MI will not only perform at a significantly higher level than the Main Ring in terms of protons delivered per cycle, but also in terms of cycle rate for antiproton production and transmission efficiency. The MI will cycle to 120 GeV every 1.5 seconds, as compared to 2.6 seconds in the Main Ring, while the aperture is sufficient for 100% transmission of antiprotons from the largest stacks imaginable. For the most part expected improvements are directly related to the optics of the MI. The MI lies in a plane with stronger focussing per unit length than the Main Ring. This means that the maximum betas are half as large and the maximum (horizontal) dispersion a third as large as in the Main Ring, while vertical dispersion is non-existent. As a result physicial beam sizes associated with given emittances are significantly reduced compared to the Main Ring. Additionally, the elimination of dispersion in the RF regions, raising the level of the injection magnetic field, elimination of sagitta (through the construction of new, curved dipoles), and improved field quality will all have a beneficial impact.

The major impact of the Main Injector on collider operations will be to increase the luminosity by a factor of 5-10 and to eliminate backgrounds in the collider detectors currently arising from the proximity of the Main Ring (which is delivering protons for antiproton production during stores). The impact on luminosity is threefold and is seen in Table I: 1)An increase in the antiproton stacking rate, due to a threefold increase in the number of protons targetted per hour, which will support a larger number of antiprotons in the collider; 2)The ability to transmit efficiently antiprotons originating in large stacks from the Antiproton Source to the Tevatron; and 3)An increase in the number of protons which can be delivered to the Tevatron in a single bunch. The third of these is important because in Phase 1, with separators implemented, the inadequacies of the Main Ring will not allow the beam-beam limit to be approached.

Other benefits anticipated from the construction of the Main Injector include an increase in the total number of protons deliverable to the Tevatron to 6×10^{13}, freeing up of a Tevatron straight section for eventual installation of a third interactiion region, provisions for slow extracted 120 GeV test beams year around and potential development of very high intensity/high duty factor ($\geq 1 \times 10^{13}$ protons/sec at 120 GeV with a 34% duty factor) beams for use in high sensitivity K decay and neutrino experiments, and the creation of space in the Tevatron enclosure for eventual installation of a second superconducting accelerator.

A description of the various operating scenarios of the Main Injector is given in Table III.

Table III: Main Injector Operational Modes

Operational Mode	Energy	Cycle Time	Flattop
Antiproton Production	120 GeV	1.5 sec	0.05 sec
Fixed Target Injection	150	3.0	0.05
Collider Injection	150	9.0	3.0
High Intensity Slow Spill	120	2.9	1.0
High Intensity Fast Spill	120	1.9	0.05

COST AND SCHEDULE

The Total Estimated Cost of the Main Injector is $129.4 M (in then-year dollars). Fermilab has proposed to complete construction of the project over the period October 1, 1990 through May 1, 1994. The construction schedule would result in a nine month disruption to High Energy Physics operations at Fermilab during the period May 1, 1993 through February 1, 1994.